

Is a State cc? cc? Found at 6.0 GeV?

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¹⁰J. Leong, quoted by Gaillard *et al.*, Ref. 1.

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¹⁴Another specific mechanism considered in Ref. 11 (see Figs. 1 and 2 thereof) was the production of χ_c or J/ψ by quark-antiquark annihilation. This mechanism should, in principle, be added to the gluon mechanism, as can be seen by replacing the produced particle by a pointlike coupling to a fictitious neutral current. [A bound on the cross section for χ_c production by this

mechanism can be derived in analogy to Eq. (1) of Ref. 11]. However, to the extent that charmonium ideas are correct so that $c\bar{c}$ annihilation occurs at very short distances, the absence of a direct local coupling of $c\bar{c}$ to ordinary quarks implies that quark annihilation is negligible compared with the gluon mechanism. This is inherent in the supposition that $\Gamma(\chi_c) \gg \Gamma(J/\psi)$.

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Is a State $c\bar{c}c\bar{c}$ Found at 6.0 GeV?

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It is pointed out that the newly discovered particle at 6 GeV may correspond to the $c\bar{c}c\bar{c}$ state which was previously predicted to exist around 6 GeV by the present author. It will decay dominantly to $J/\psi(3.1) + \eta_c(2.8)$.

One year ago, the present author¹ predicted a $c\bar{c}c\bar{c}$ resonance state at about 6.2 GeV based on a model of charm and exotics. Recently a new resonance² at about 6.0 GeV was reported. It is quite natural to consider that the newly discovered resonance corresponds to what was predicted in Ref. 1.³ In this Letter this possibility will be examined in detail and possible tests of the model will be given.

In the present model the $J/\psi(3.1)$ meson is assigned to a vector meson $c\bar{c}$, as is usual in the charm scheme, while the $\psi(3.7)$ meson is assigned to an exotic meson $c\bar{c}(u\bar{u} + d\bar{d})$. Two resonances, $c\bar{c}(u\bar{u} - d\bar{d})$ ($I=1$) and $c\bar{c}s\bar{s}$ ($I=0$), were predicted in Ref. 1 between ~ 3.7 and ~ 4.1 GeV, as well as another resonance $c\bar{c}c\bar{c}$ at 6.2 GeV. As a rough estimate for the masses of these resonances, I used the sum of the quark masses, assuming $m_u = m_d = 300\text{--}400$ MeV, $m_s \sim 500$ MeV, and $m_c \sim 1550$ MeV.

The states $q\bar{q}q\bar{q}$ belong to $84 \oplus 15 \oplus 1$ in the SU(4) symmetry if two quarks and two antiquarks are symmetric (symmetric states), respectively, in the SU(4) indices, while they belong to $20 \oplus 15 \oplus 1$ if two quarks and two antiquarks are antisymmetric (antisymmetric states). The other states belong to $45 \oplus 45^* \oplus 15 \oplus 15$ where two quarks are

symmetric and two antiquarks are antisymmetric or vice versa (mixed-symmetry states). The model in Ref. 1 corresponds to the symmetric case (Model I).

An alternative model (Model II) is the one where both the symmetric and antisymmetric states exist. In this model there are six exotic vector mesons $c\bar{c}q'\bar{q}'$ (two $I=1$ and four $I=0$ states), where q' stands for u, d , or s . Note that there are three states in Model I. These states correspond to resonances between 3.7 and 4.4 GeV. I assume that the mixed-symmetry states exist at the higher mass region or do not exist as resonances at all.

I do not discuss here the complications due to spin and orbital angular momenta and just assume that there is a vector meson corresponding to each unitary spin state. I shall discuss the details of the models which depend on dynamics, as well as the justification of the assumptions made here and above, in a separate paper.

The choice between the two models is reserved for future investigation when more experimental data are available. (There are also other variations than Model I and Model II.) I refer to $c\bar{c}(u\bar{u} + d\bar{d})$, $c\bar{c}(u\bar{u} - d\bar{d})$, $c\bar{c}s\bar{s}$, and $c\bar{c}c\bar{c}$ as ψ_ω , ψ_ρ , ψ_φ , and ψ_ψ , respectively. (Note that there are two ψ_ω ,

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per limit (90% confidence level) for the radiatively corrected integrated cross section of a possible narrow resonance is 450 nb MeV in the mass region 5.90 to 7.60 GeV. This number corresponds to

$$\Gamma_{ee} \leq 700 \text{ eV}. \quad (6)$$

It should be noted that if the new resonance is a pair state of a new quark with $Q = \frac{2}{3}$ (or $Q = \frac{1}{3}$), the particle width to an electron pair is naively $\Gamma_{ee} = 4 \text{ keV}$ (or $\Gamma_{ee} = 1 \text{ keV}$), which the author regards as being in contradiction to (6). Although we cannot predict the partial width in the present model, we can stay within the experimental limit.

Let us assume, just as an example, that $\Gamma_{ee} = 300 \text{ eV}$, $\Gamma_{\text{tot}} = 150 \text{ keV}$, and $\sigma(p + N \rightarrow \psi + X) = \frac{1}{50} \sigma(p + N \rightarrow J/\psi(3.1) + X)$. Then we obtain

$$\begin{aligned} \sigma(p + N \rightarrow \psi + X) \\ \quad \quad \quad \downarrow l\bar{l} \\ \simeq \frac{1}{2000} \sigma(p + N \rightarrow J/\psi(3.1) + X), \quad (7) \\ \quad \quad \quad \downarrow l\bar{l} \end{aligned}$$

which is consistent with the experiment.² These numbers are not predictions and are given just to show that the present model is consistent with the experiment.

Exotics without charmed quarks.—The model predicts a lot of exotic mesons without the charmed quark in the mass region between about 1.5 and 2.2 GeV. Although there are several candidates,⁸ none of the hadrons are identified definitely as exotics. This may seem to be a difficulty in the model. I do not, however, consider it as a difficulty for the following reasons:

(i) The spectroscopy above 1.5 GeV is not satisfactory except for the leading trajectories. For example, the ψ' meson which is an SU(3) partner of the $\rho'(1600)$ meson has not been discovered and the ω' meson has not been observed, at least in e^+e^- annihilation, although I do not necessarily assume that these mesons are exotics. I hope

that more extensive searches for exotic mesons will reveal their existence. For example, an exotic meson such as $(u\bar{u} + d\bar{d})(u\bar{u} - d\bar{d})$ will decay to $\rho 2\pi$ with a width of several MeV.

(ii) The possible existence of exotics does not make invalid the success of the duality without exotics, since the trajectory of the exotic meson will lie much below the leading trajectory, at the position which corresponds to the second daughter.

(iii) The model predicts a doubly charged meson such as $u\bar{d}u\bar{d}$ around 1600 MeV. The decay to $\pi^+\pi^+$ might be suppressed compared with many-body decays such as $\rho^+\pi^+\pi^0$.

(iv) The production of exotic mesons in hadronic reactions (such as πN or NN reaction) may be suppressed compared with ordinary mesons.¹

In conclusion, the present model is consistent with the experiment. A crucial test for the model is whether the new resonance at 6 GeV does decay dominantly to $J/\psi(3.1) + \eta_c(2.8)$.

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